ANALYSIS OF CONTROL METHODS FOR BUCK DC-DC CONVERTER

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A report submitted in partial fulfillments of the requirement of the Degree of Bachelor of Electrical Engineering (Power Systems)

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JUNE 2012

ABSTRACT

A DC to DC converter is an electronic circuit which converts a source of direct current (DC) from one voltage level to another. There are three main topologies of converters which are buck converter, boost converter and buck-boost converter. This project is focus on Buck dc-dc converter using the hysteresis, PID and three-level hysteresis controllers. The buck dc-dc converter used to step down the input dc voltage from 24V to 12V. The hysteresis, PID and three-level hysteresis controllers are applied to control the switching of the switching device in buck converter so that the output voltage can be maintained 12V. The PID controller is the most common used in feedback control. The good output voltage can be obtained by well-tuning the P, I and D gains. The hysteresis control is a simplest method and inexpensive and easy in designing. The hysteresis band is derived from the converter current to predict the output voltage after the switching action. The term PID is defined as P for proportional, I for integral and D for derivative. The complete converter circuit is designed and implemented in MATLAB Simulink software. The analyses are carried out by make a comparison of the output voltage and load changes for all controllers.

ABSTRAK

Penukar DC ke DC ialah litar elektronik yang menukarkan sumber arus terus (DC) dari satu tahap voltan ke tahap yang lain. Terdapat tiga topologi utama penukar iaitu ‘buck converter’, ‘boost converter’ dan ‘buck-boost converter’. Projek ini memfokuskan kepada penukar ‘buck converter’ menggunakan histerisis, PID dan tiga tahap histerisis sebagai pengawal. ‘Buck converter’ akan menukarkan voltan masuk dari 24V kepada 12V. Kawalan histerisis, pengawal PID dan tiga tahap histerisis kawalan digunakan untuk mengawal suis di penukar buck supaya voltan keluaran boleh dikekalkan 12V. Kawalan histerisis adalah satu kaedah pengawalan yang paling mudah dimana pampasan tidak diperlukan. Jalur histerisis berasal dari penukar semasa untuk meramalkan voltan keluaran selepas tindakan menukar. Pengawal PID pula adalah pengawal maklum balas yang paling biasa digunakan. PID ditakrifkan sebagai P untuk berkadar terus, I untuk kamir dan D untuk pembezaan. Litar penukar yang lengkap direka dan dilaksanakan dalam perisian MATLAB Simulink. Analisis dijalankan dengan membuat perbandingan voltan keluaran dan perubahan beban untuk semua pengawal.

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LIST OF ABBREVIATIONS

DC	Direct current
Vi	Voltage input
Vo	Voltage output
S	Switch
D	Diode
R	Resistor
L	Inductor
C	Capacitor
PWM	Pulse width modulation

CHAPTER 1

INTRODUCTION

1.1 Introduction

Dc-dc converter is a switching circuit which transforms the voltage of the dc source (Vi) into other desired voltage in the load side (Vo). This is achieving through a suitable switching process of the circuit. The dc-dc converters are widely used in regulated switching-mode DC power supply and in DC motor drive application [1]. For dc-dc converter, there are three main topologies which are buck converter (step-down), boost converter (step-up) and buck-boost converter (step down and up).

A buck converter or step-down switch mode power supply can also be called a switch mode regulator. Buck converter produces a lower average output voltage than the DC input voltage, V_i. When the switch *S* is on, the diode *D* in Figure 1.1 become reverse biased and the input provides energy to the load as well as to the inductor. While, when the switch is off, the inductor current flows through the diode *D*, transferring some of its stored energy to the load *R* [1][2].

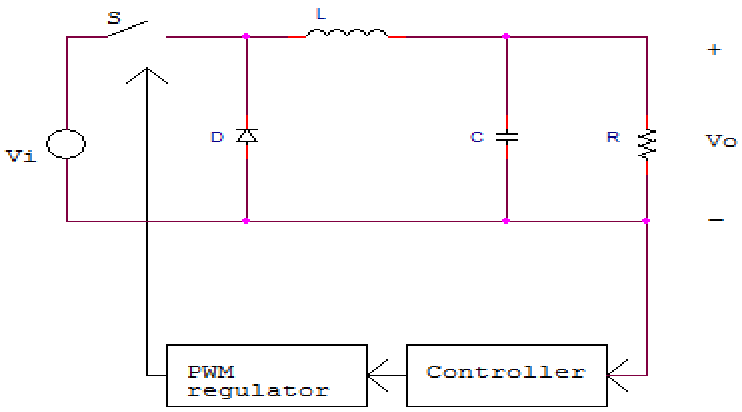

Figure 1.1: Buck converter

A boost converter or step-up converter is a power converter with an output DC voltage greater than its input DC voltage. The circuit of boost converter is shown in Figure 1.2. When the switch *S* is on, the diode *D* is reversed bias, thus isolating the output stage. The input supplies energy to the inductor. When the switch is off, the output stage receives energy from the inductor as well as from the input. The boost main application is in the regulated dc power supplies and the regenerative braking of dc motors [1].

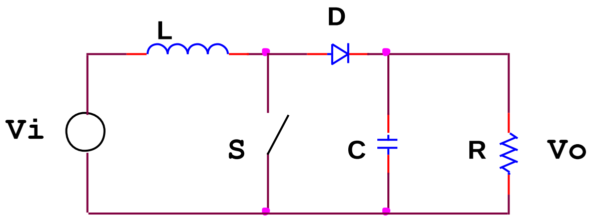

Figure 1.2: Boost converter

The buck–boost converter is a converter that has an output voltage that is either greater than or less than the input voltage. Buck-boost converter can be obtained by the cascade connection of the two basic converters which are the step down converter and step up converter. These two converters can be combined into the single buck- input provides energy to the inductor and the diode is reverse biased.

When the switch *S* is open, the energy stored in the inductor is transferred to the output [1]. No energy is supplied by the input during this interval. The main application of buck-boost converter is in the regulated dc power supplies.

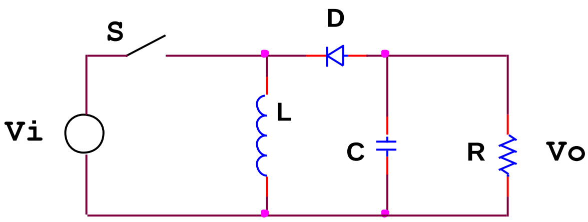

Figure 1.3: Buck-boost converter

From the mentioned topologies, the buck converter will be used in this thesis. Three types of controllers are proposed and approach to the converter i.e. PID, hysteresis control and three level hysteresis controllers. The hysteresis control is the one of the simplest control method besides PID. Hysteresis control also known as bang-bang control or ripple regulator control, maintains the converter output voltage within the hysteresis band centred about the reference voltage [3]. The hysteretic-controlled regulator is popular because of its inexpensive, simple and easy to design. The greatest benefit of hysteresis control is that it offers fast load transient response. The other well-known characteristic is the varying operating frequency.

The PID controller also implemented to buck dc-dc converter. PID controller can be viewed as three terms which is a proportional term, integral term and derivative term. PID controllers are also known as three-term controllers and three mode controllers. The PID is so popular among other controller because using PID gives the user a large number of options and those options mean that there are more possibilities for changing the dynamics of the system in a way that helps the users. Besides that a derivative control terms often produces faster response [4]. Figure 1.4 shows a block diagram of PID controller.

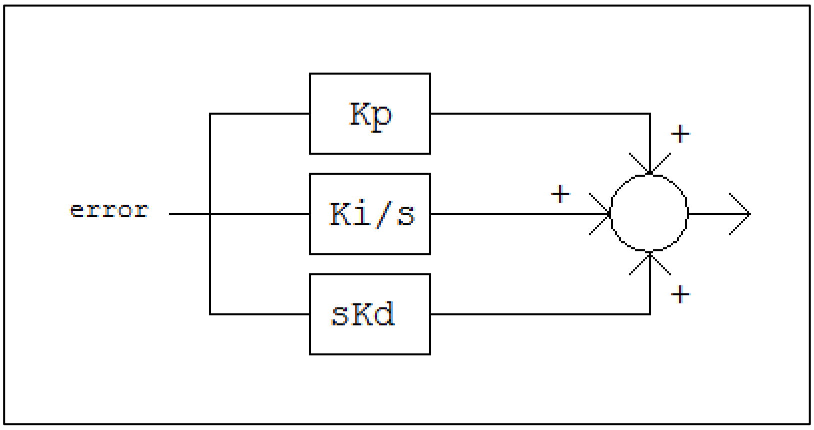

Figure 1.4: PID diagram

1.2 Problem Statement

a) The dc-dc converter is difficult to control since it depends on the switching characteristic to control the output voltage.

b) The dc-dc converter is difficult to obtain a good transient response.

1.3 Objective

a) The propose of this project is to analysis various control methods approach to buck dc-dc converter.

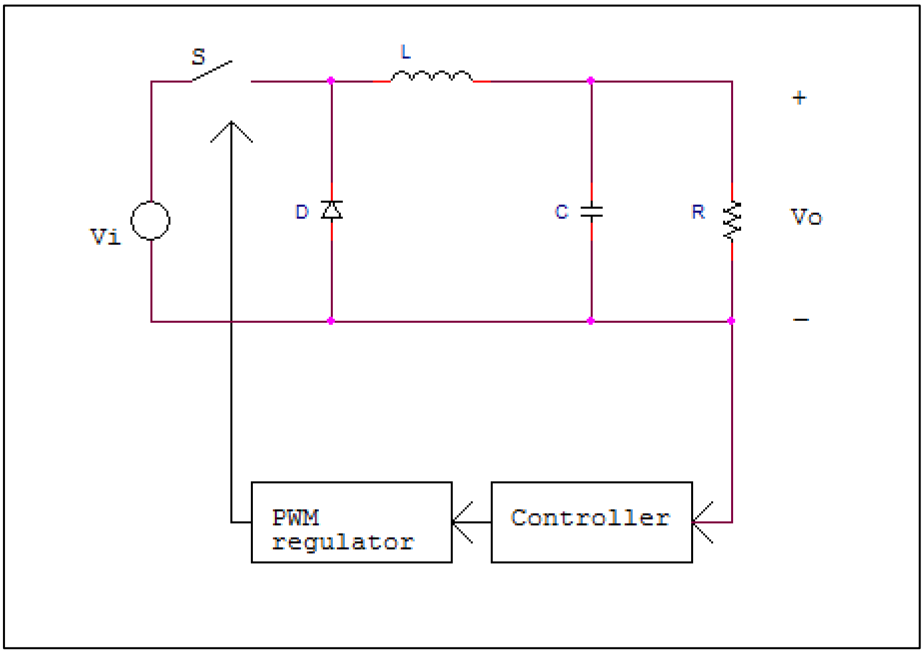

Figure 1.5: Controller with buck converter

b) To simulate the proposed controllers and make a comparison among them.

1.4 Project Scope

The scope of this project is to design the hysteresis controller, PID controller and three-level hysteresis control and implemented it to buck dc-dc converter by using matlab Simulink. The results of simulation will be analysed and compared.

1.5 Outline of Thesis

Chapter 1 consists of the overview of the project, which includes the problem statement, objectives and scope.

Chapter 2 summarizes all the paper works and related research as well as the studies regards to this project. This literature reviews all important studies which have been done previously by other research work.

Chapter 3 illustrates the operation and the parameters involved in the dc-dc buck converter. The controller that approach to dc-dc buck converter is described in detail.

Chapter 4 presents the simulation design of the dc-dc buck converter using MATLAB/Simulink. It also consists of the simulation results and discussion based on different controller.

Chapter 5 concludes the overall thesis and for future work.

CHAPTER 2

LITERATURE REVIEW

This chapter includes all the paper works and related research as well as the studies regards to this project. This literature reviews all important studies which have been done previously by other research work. The related works have been referred carefully since some of the knowledge and suggestions from the previous work can be implemented for this project. Literature review has been done continuously throughout the whole process of the project. It is very essential to refer to the variety of sources in order to gain more knowledge and skills to complete this project.

2.1 Operation of buck dc-dc converter

The three basic dc-dc converters use a pair of switches, usually one controlled and one uncontrolled, to achieve unidirectional power flow from input to output. The converters also use one capacitor and one inductor to store and transfer energy from input to output. They also filter or smooth voltage and current. The dc-dc converters can have two distinct modes of operation which is continuous conduction mode (CCM) and discontinuous conduction mode (DCM). [1][5]

When the switch is on for a time duration DT, the switch conducts the inductor current and the diode becomes reverse biased. This results in a positive voltage $v_L = V_g - V_o$ cross the inductor. This voltage causes a linear increase in the inductor current iL as shown in Figure 2.1. When the switch is turned off as shown in Figure 2.2, because of the inductive energy storage, iL continues to flow. This current now flows through the diode, and vL = -Vo for a time duration (1-D)T until the switch is turned on again. Figure 2.3 shown the buck converter waveform.[1][5]

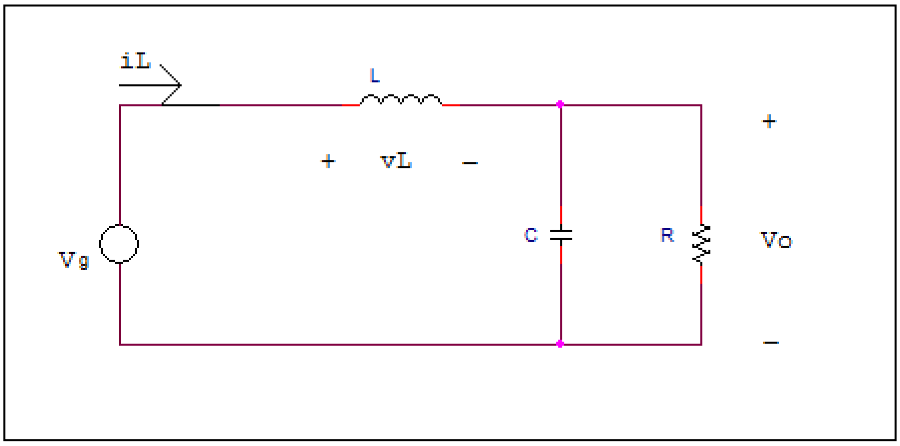

Figure 2.1: On mode

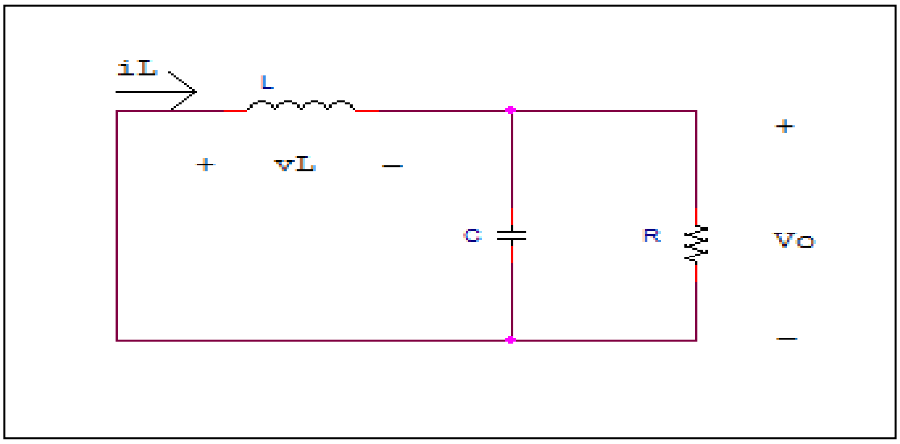

Figure 2.2: Off mode

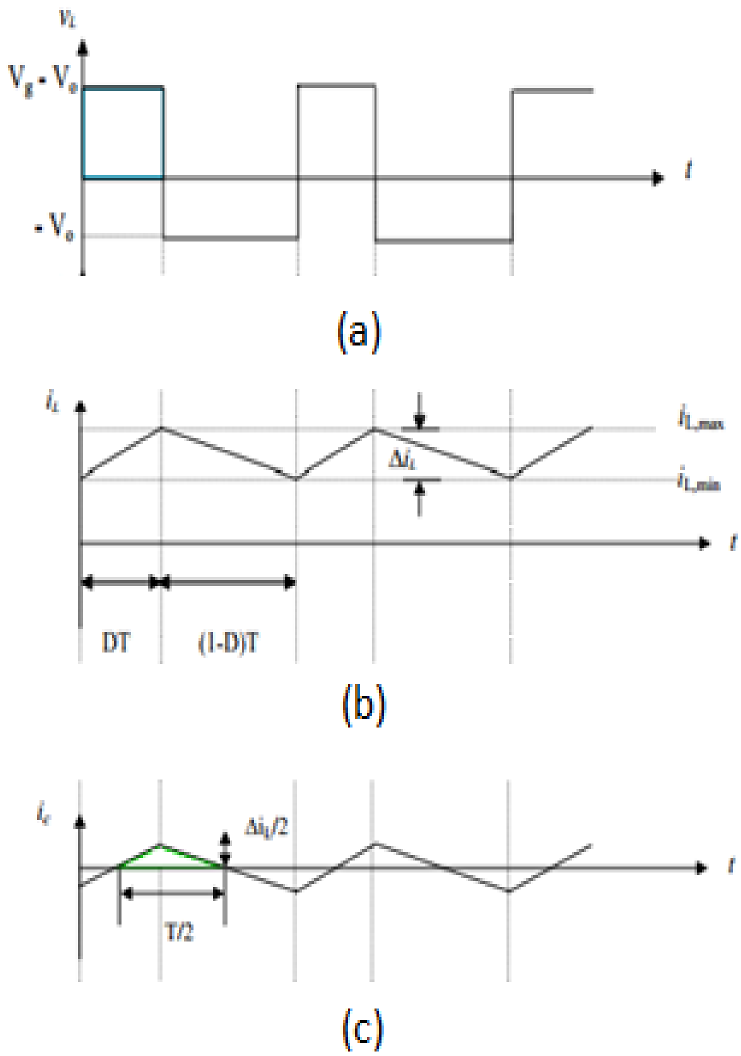

Figure 2.3: Buck converter waveforms; (a) inductor voltage; (b) inductor current; (c) capacitor current

2.2 Hysteresis Controller

V.M. Nguyen and C.Q. Lee (1995) entitlement, the ripple regulator is another name for the hysteresis control in which the error amplifier has been used to cancel the low-frequency poles of the output filter and to push the system closed-loop bandwidth up to high-frequency, while maintaining a high gain at low frequency. The tracking control law using state-feedback which has been used successfully in some other control applications can now be applied to control a general buck converter and as a result the response has been observed to be very fast and the waveform errors are minimized.[6]

Kelvin Ka-Sing Leung and Henry Shu-Hung Chung (2005) entitlement, the hysteresis band is derived from the output capacitor current that predicts the output voltage magnitude after a hypothesized switching action. The state-trajectory-prediction can effectively enhance the transient response of the buck converter using hysteresis control without significant modification in the control circuit. It can operate in both continuous and discontinuous conduction modes. The output can revert to the steady state in two switching actions after a large-signal disturbance.[7]

Szepesi and Thomas (1987) entitlement, a systematic investigation of methods to stabilize the operating frequency of hysteretic current-mode dc to dc converters through control of the current hysteresis is presented. The most commonly used peak current programmed mode the frequency control decreases the phase margin and can make the loop unstable. Using average current control, on the other hand, does not influence the dynamics of the voltage control loop; consequently, it is superior to the peak-current programmed version.[8]

L.K. Wong and T.K. Man (2008) entitlement, a hysteretic control buck converter is inherently a variable structure system owing to the presence of switching actions. Analysis results show the relationship between the steady state performance and a number of parameters, in particular the output capacitor's ESR. If the ESR is too small, the output voltage ripple will increase significantly and a phase shift is resulted. Hysteretic control response to disturbances and load change right after the transient take place so they give excellent transient performance.[9]

A. Borrell, M. Castilla, J. Miret, J.Matas and L. G. Vicuna (2011) entitlement, hysteretic controller for a multiphase synchronous buck converter supplying low voltage, high current, and high slew-rate loads. The control scheme implements the main control functions for powering such demanding loads, including output-voltage regulation, adaptive voltage positioning, current sharing, and phase interleaving. A control-design methodology based on output impedance analysis leads to optimal output-voltage transient response with a simple and low-cost control implementation.[10]

C.T. Tsai and H.P. Chou (2009) entitlement, an integrated DC-DC buck converter using the synthetic ripple hysteresis control scheme with a fast transient path to define the boundary of hysteresis band. The hysteresis band and switching frequency depend on load current changes. Therefore, it accelerates regulation and reduces overshoot. The ripple signal sensed from inductor current or output voltage is confined within a hysteretic band and used to control the power MOSFETs with simple logic gates. Hysteresis control is self-stabilized so additional frequency compensation capacitor is not needed. Therefore, leads to a very fast response.[11]

S. C. Huerta, P. Alou, J. A. Oliver, O. Garcia, J. A. Cobos and A. Abou-Alfotouh (2009) entitlement, the combination of non-linear control and linear control proposed in provides very fast transient response. This non-linear control is based on hysteretic control of the Cout current. This system is very sensitive to effects like aging, temperature, input and output voltage variation. This paper proposes a frequency loop to avoid the frequency variation and to adjust the switching frequency to the nominal value by changing the hysteretic band.[12]

T. Nabeshima, T. Sato, S. Yoshida, S. Chiba and K. Onda (2004) entitlement, the control circuit consists only of a comparator with a hysteresis and neither error amplifier nor a clock generator is used. The control signal voltage supplied to the comparator is obtained from a simple RC network connected to the inductor winding. The steady-state output voltage and the switching frequency are initially examined taking the propagation delay in the controller into account. The dynamic characteristics is then analysed both in frequency and time domains.[13]

2.3 PID controller

Hyun-Hee Park, Young-Jin Woo and Gyu-Hyeong Cho (2011) entitlement, to design a fully integrated compensator that is not sensitive to the output stage noise. In addition, an error amplifier is implanted without an additional compensation capacitor. To ensure fast load transient, it is required for such a compensator to have a wide bandwidth around 1/5 to 1/10 of the switching frequency and to be less sensitive to switching noise or high frequency poles. Therefore, the poles and zeros should be adjusted to proper values ensuring a total loop bandwidth.[14]

S. Chander, P. Agarwal and I. Gupta (2011) entitlement, an improved discrete auto-tuning PID scheme is developed for DC-DC converters where large load changes are expected or the need for fast response time. To improve the transient response and rise time of the converter, the controller parameters are continuously modified based on the current process trend.[15]

Hongmei LI and Xiao Ye (2010) entitlement, a sliding-mode PID controller is presented for controlling the DC-DC converter and the researches have validated that the system has good dynamic performance and fast system response. The unified dynamical model of DC-DC buck converter is set up and two sliding mode controllers are introduced called conventional sliding mode controller and sliding mode proportional integral derivative (PID) controller. The stability are analyzed for the DC-DC converter system controlled by the sliding mode PID, and the optimum sliding mode PID parameters are determined.[16]

2.4 Three level hysteresis control

The paper proposes a series resonant power converter that is driven by a pulse density modulation strategy combined with a three level hysteresis controller to adjust output power. The first part of the closed-loop regulation strategy is an anticipation loop. This instrument represents the inverse process of the system. It gives the sequence of modulation that corresponds to a given output power. The desired output power will be the entry for this sub-system. The goal is to increase the system's speed response. A three-level hysteresis controller permits the system to oscillate between modulation sequences in order to get an average output power delivered to the load, near the desired one.[17]

The paper presents a simple and effective method of implementing single phase hysteresis current regulation as a three level modulation process. The switching process is shown in figure 2.4 and 2.5 where the current error is bounded between the upper inner and lower outer hysteresis boundaries for a positive inverter output and between the lower inner and upper outer hysteresis boundaries for a negative inverter output. The new switching process introduces a positive or negative dc offset error into the average output current depending on the polarity of the active output voltage.[18]

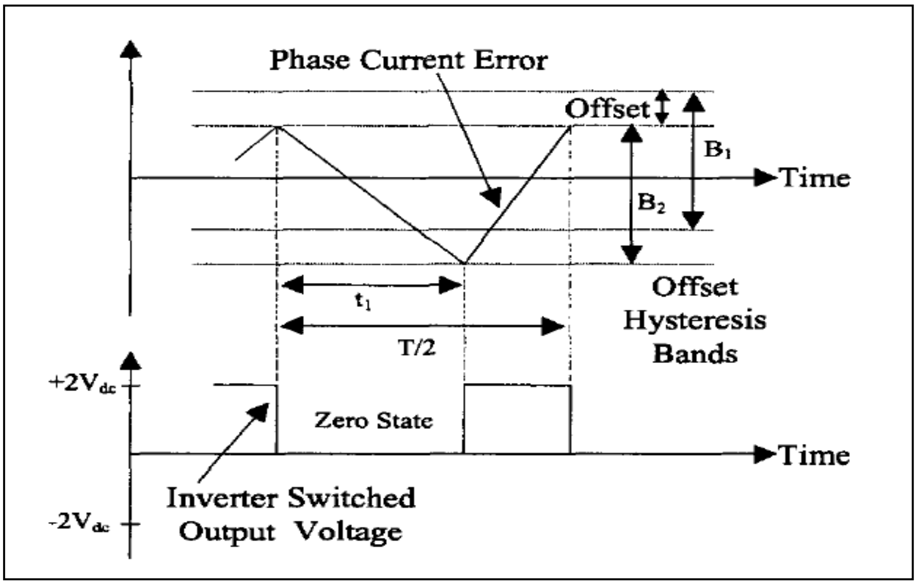

Figure 2.4: Positive inverter output

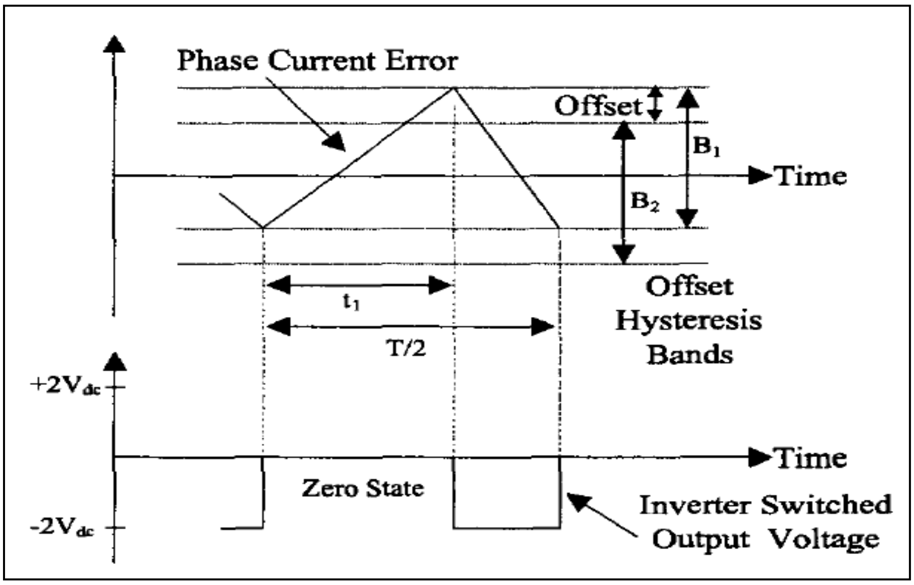

Figure 2.5: Negative inverter output

CHAPTER 3

METHODOLOGY

This study is using matlab Simulink to design the buck converter using different controller which is hysteresis controller, PID controller and three-level hysteresis control. The methodology of this project consist several steps as shown in Figure 3.1. This project begins with a through literature review on the basic concept of dc-dc buck converter. The theory of dc-dc buck converter is very important in this project in order to get clear understanding on what the project is all about.